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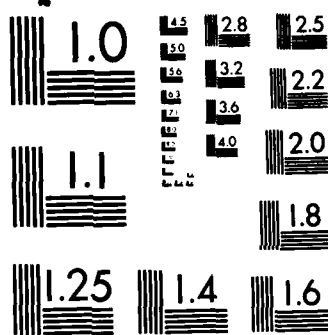
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1985/86 Annual Report

for the Period: 1 April 1985 - 31 December 1985

Submitted by:

University of Southern California  
University Park  
Los Angeles, California 90089-0483

*William H. Steier*  
William H. Steier, Director  
Joint Services Electronics Program

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## **DIRECTOR'S OVERVIEW**

This report summarizes the progress made under the Joint Services Electronics Program for the period 1 April 1985 to 31 December 1985. It is the first annual progress report on the three-year contract, F49620-85-C-0071. The report covers the thirteen research projects being supported: three in Solid State Electronics, four in Quantum Electronics, and six in Information Electronics.

The report also summarizes the Significant Accomplishments that have been achieved during this research period.

## **SIGNIFICANT ACCOMPLISHMENTS**

### **Optimized MBE Growth Conditions for MQW Structures - Anupam Madhukar, Research Unit SS1-2**

The unique MBE Growth conditions to optimize the structural and chemical morphology of  $\text{GaAs}/\text{Al}_x\text{Ga}_{1-x}\text{As}$  heterojunctions have been defined. These growth conditions have resulted in extremely high interfacial quality MQW structures.

### **Improvement in the High-Speed Time Response of Photorefractive Materials - Jack Feinberg, Research Unit QE1-4**

By oxidation and reduction treatment of  $\text{BaTiO}_3$  crystals, the time response of the photorefractive effect was made to be linearly proportional to the optical intensity. This has particular application to the use of phase conjugators to correct optical distortions present in a resonator cavity.

### **Estimation of Object Motion Parameters from a Sequence of Noisy Images - Rama Chellappa, Research Unit IE1-7**

An algorithm for estimating object motion parameters from a sequence of 20-30 noisy image frames has been developed. This technique permits a desired degree of smoothing to be achieved through the use of an arbitrarily large number of frames.

## **HETEROJUNCTION MATERIALS AND DEVICES EMPLOYING ULTRATHIN LAYERS GROWN BY METALORGANIC CHEMICAL VAPOR DEPOSITION (MOCVD)**

**P. D. Dapkus  
Research Unit SS1-2**

### **PROGRESS**

Significant progress in the growth of AlGaAs and GaAs materials and devices structures in our laboratory. Some of this work has been supported on a separate program with K. Malloy of AFOSR. High luminescence efficiency GaAs and AlGaAs has been grown with acceptable background impurity levels ( $\sim 10^{15} \text{ cm}^{-3}$ ). The composition of the alloy as a function of growth parameters and conditions has been determined and heterojunction structures have been grown. Single and double heterostructure samples of various compositions have been analyzed by room temperature and low temperature photo-luminescence (PL). During the course of these studies it was determined that compositional fluctuations were occurring in the AlGaAs after the formation of a heterojunction. These fluctuations cause localized layers of varying composition that resulted in large PL line widths and apparently random PL emission wavelength. The presence of these fluctuations were confirmed by SIMS and TEM measurements. The cause of these fluctuations is thought to be a pressure imbalance in the reactor vent and growth lines. Steps are being taken to eliminate these imbalances.

Studies of diffusion induced disordering of superlattices has been undertaken to determine its potential role in device fabrication. Single ultrathin ( $100\text{\AA}$ ) layers of AlAs imbedded in GaAs were subjected to low temperature ( $550^\circ\text{C}$ ) Zn diffusion using a  $\text{Zn}_2\text{As}_3$  source. The profile of Al in the structure was determined by using SIMS analysis in collaboration with Jet Propulsion Laboratory. We have determined that the Al interdiffuses a distance of  $\sim 100\text{--}200\text{\AA}$  during a 2 hour Zn diffusion. A flat  $400\text{\AA}$  thick with a flat Al profile was achieved by treating a sample containing a  $100\text{\AA}$  thick AlAs layer,  $200\text{\AA}$  below the surface of GaAs layer. Surface accumulation of the Al occurred for greater diffusion times. It was also determined that the diffusion constant of the Al is significantly lower than that of the Zn. This observation leads us to conclude that the utility of Zn diffusion as a means of disordering thin layers is limited.

We have been exploring the use of AlGaAs heterojunctions grown by MOCVD in new device structures. This has lead us to examine the Pnp heterojunction bipolar transistor (HBT). It has been standard to use the Npn structure in HPT's owing to the high mobility of electrons in III-V semiconductors. Our analysis shows that this high mobility might better be used to reduced the base resistance in Pnp structures because transit across the base is usually a small fraction of the total time delay in an HBT. In fact, compact device analysis of Npn and Pnp microwave and switching transistors has shown that, with realistic device dimensions, the Pnp is comparable to an Npn structure in both frequency of operation and switching speeds. A preprint of this paper is included.

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| ZI            | 01 |
| ZJ            | 01 |
| ZK            | 01 |
| ZL            | 01 |
| ZM            | 01 |
| ZN            | 01 |
| ZO            | 01 |
| ZP            | 01 |
| ZQ            | 01 |
| ZR            | 01 |
| ZS            | 01 |
| ZT            | 01 |
| ZU            | 01 |
| ZV            | 01 |
| ZW            | 01 |
| ZX            | 01 |
| ZY            | 01 |
| ZZ            | 01 |



A1



## SOME INVESTIGATIONS OF THE KINETICS AND MECHANISM OF MOLECULAR BEAM EPITAXIAL GROWTH

A. Madhukar  
Research Unit: SS1-2

### PROGRESS

The task proposed under work unit SS4-2 defined its objective to be an examination of the kinetics and growth mechanism(s) of GaAs/ $\text{Al}_x\text{Ga}_{1-x}\text{As}$  MBE via the in-situ use of reflection-high-energy-electron-diffraction (RHEED) and cross-sectional transmission electron microscopy (XTEM).

Our in-situ, real-time investigations of the RHEED pattern and intensity dynamics continued during this reporting period and led to the identification of many unique features of the surface and interface step density distributions as a function of the growth conditions employed. For brevity we note only two of the several findings:

1. The RHEED studies revealed the existence of certain unique growth conditions for which the underlying surface kinetic processes controlling the structural and chemical morphology of the normal (i.e.  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  deposition on GaAs) and inverted (i.e. GaAs deposition on  $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ) interface can be simultaneously optimised. An example of such a behavior is shown in Fig. 1. Plotted is the behavior of the static (i.e. no growth) GaAs surface and the steady state (i.e. during growth) GaAs and AlAs specular beam intensities as a function of  $\text{As}_4$  pressure at the chosen substrate temperature of  $650^\circ\text{C}$  and growth rates of 2 secs./monolayer (panel a) and 4 secs./monolayer (panel b). The inset on top provides a typical behavior of the oscillations and serves to identify the static ( $I_0$ ) and steady state ( $I_S$ ) regimes of the intensity. Note that while in panel (a) the maximum in  $I_0$  (GaAs),  $I_S$  (GaAs) and  $I_S$  (AlAs) occur at three different  $\text{As}_4$  pressures of  $4 \times 10^{-6}\text{Torr}$ ,  $2\text{--}3 \times 10^{-6}\text{Torr}$  and  $\geq 6 \times 10^{-6}\text{Torr}$ , a slowing down of the growth rate by a factor of 2 leads to the unique situation of panel (b) -- namely, all three maximum occur at the same  $\text{As}_4$  pressure of  $4 \times 10^{-6}\text{Torr}$ . To the extent that the specular beam intensity is inversely related to the surface step density distribution, identification of growth conditions for which all three,  $I_0$  (GaAs),  $I_S$  (GaAs) and  $I_S$  (AlAs) are simultaneously maximum suggests that such growth conditions are uniquely suited for realization of high quality multiple quantum well (MQW) structures, without the need for optimizing the conditions (such as choice of two different  $\text{As}_4$  pressures) for each individual layer.

2. As another example of our findings, in Fig. 2 we show the specular beam dynamics during growth of ultra-thin  $(\text{GaAs})_n/(\text{AlAs})_n$ ,  $n=2$  and 6, MQW structures and superlattices, under the uniquely optimized conditions of Fig. 1(b). Several important features of pragmatic value for realization of high interfacial quality MQW are seen for the first time. These are;

(A). Comparison of curves (a) and (c) shows that increase in individual layer thickness from 2 to 6 monolayers has a significant effect on continued degradation of normal (AlAs on GaAs) and inverted (GaAs upon AlAs) interfaces with continued growth (i.e. increasing total superlattice thickness) under the customary practice of no growth interruption).

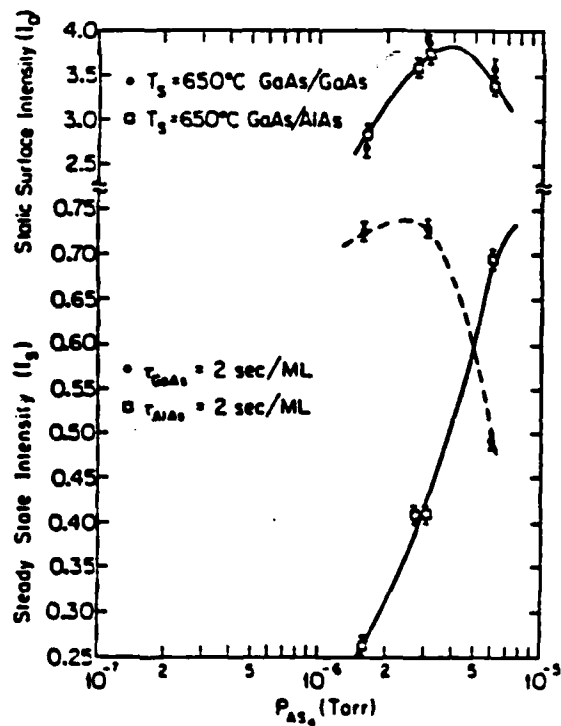
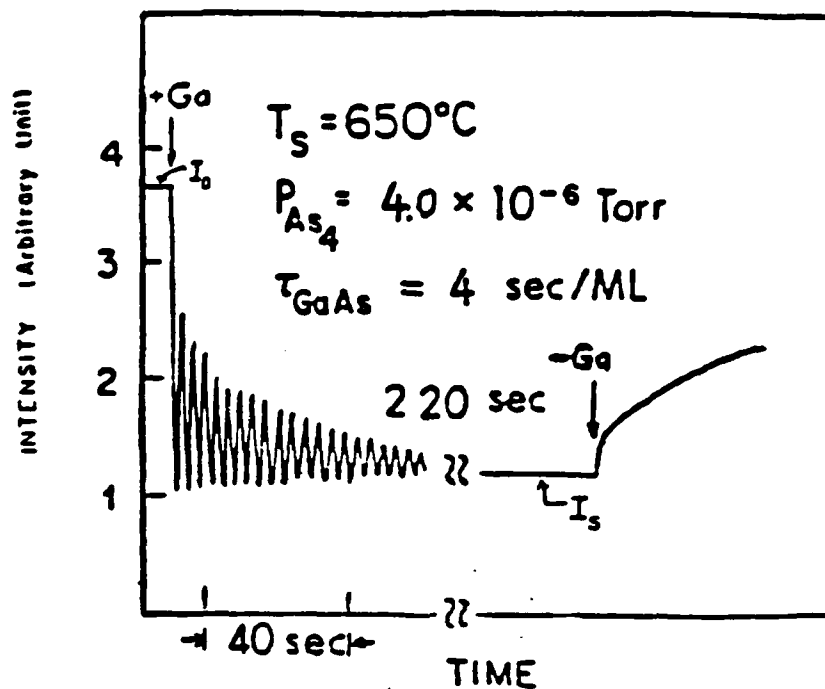
(B). Comparing curve (b) to (a) and (d) to (c) one sees that the new concept of growth interruption achieves two important improvements in the interfaces:

(B.1) At 2 monolayer thickness of individual layers, growth interruption for both AlAs and GaAs gives rise to sufficient intensity recovery to improve both inverted and normal interfaces and also prevent degradation with continued growth.

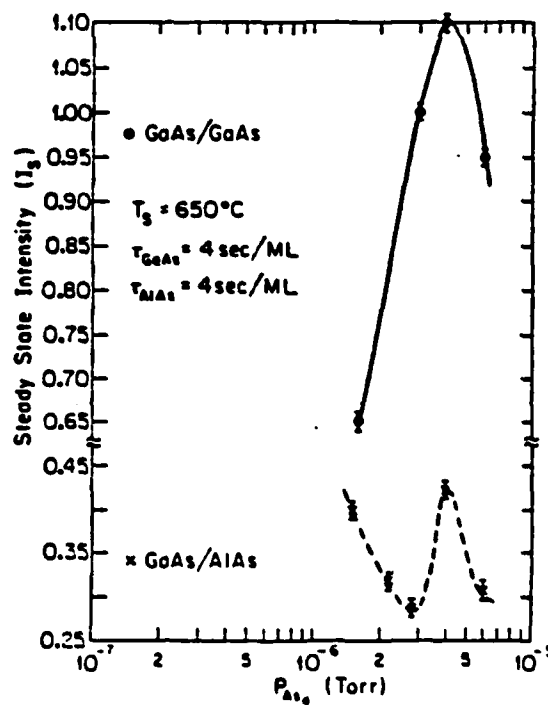
(B.2) At 6 monolayer thickness, even though the slower surface migration kinetics of Al does not help improve the inverted interface, the faster kinetics of Ga not only improves the normal interface, it also prevents propagation of the adverse nature of the first inverted interface to the subsequent normal and inverted interfaces.

#### LIST OF PUBLICATIONS:

1. "Kinetics of the Formation of Normal and Inverted Molecular Beam Epitaxial Interfaces: A RHEED Dynamics Study of  $\text{GaAs}/\text{Al}_x\text{Ga}_{1-x}\text{As}(100)$  Multiple Quantum Wells", M.Y. Yen, T.C. Lee, P. Chen and A. Madhukar, J. Vac. Sci. Tech. B (Mar./Apr. '86 Issue, In Press).



(a)



(b)

Fig. 1

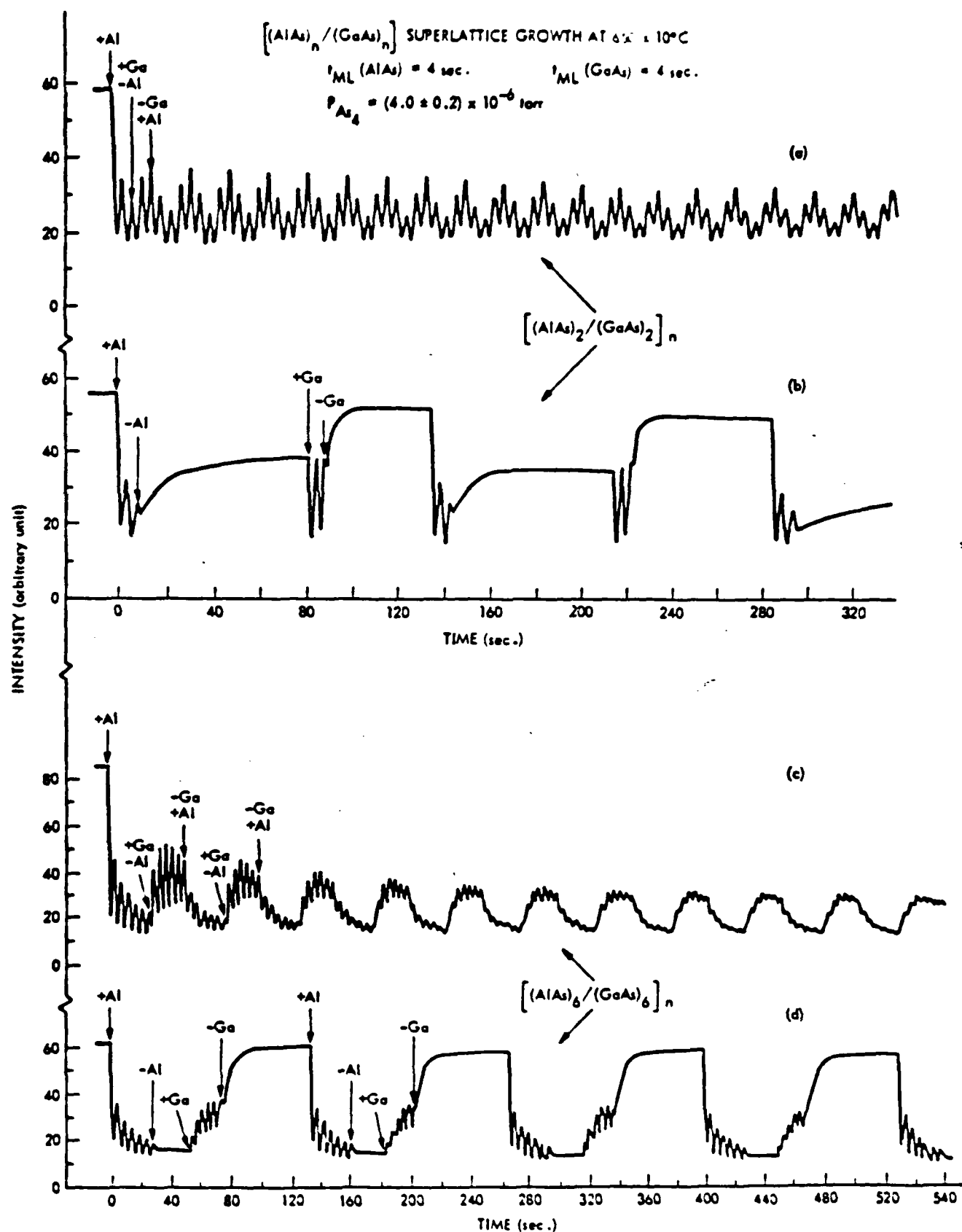


Fig. 2

## **ELECTROOPTIC MATERIALS FOR OPTICAL PROCESSING AND COMPUTING DEVICES**

**Armand R. Tanguay, Jr.  
Research Unit SS2-3**

### **PROGRESS**

During the most recent contract period, significant progress has been achieved in three interrelated areas, as described in succeeding paragraphs. Progress on the development of the Photorefractive Incoherent-to-Coherent Optical Converter (PICOC), a novel two-dimensional spatial light modulator explored under this contract, included imaging studies in an optimized wave vector matching condition that gave rise to greatly increased resolution. In addition, the polarization properties of the PICOC device were studied using new techniques described below.

The PICOC device is but one of many volume holographic optical elements utilizing photorefractive bismuth silicon oxide, which is both electrooptic and optically active. This combination of optical properties gives rise to striking polarization effects that can be used to significantly increase, for example, the signal-to-noise ratio of holographic image reconstruction by polarization discrimination between the scattered and diffracted beams. During the contract period, this process of diffraction in electrooptic and optically active media was studied analytically for the first time by coupled wave analysis, as detailed in JSEP Pub. 1. This method allows extensive modeling of the diffraction process for device and system optimization.

Also during the contract period, a method of solving coupled wave diffraction problems with arbitrary polarization effects was derived as an extension of the optical beam propagation method. This new anisotropic optical beam propagation method is extremely computationally efficient, and yields orders of magnitude improvement over alternatives such as matrix diagonalization and iterative differential equation solution algorithms. Details of the method and our application thereof to a wide variety of interesting and important problems is provided in JSEP Pub. 2.

### LIST OF PUBLICATIONS

1. A. Marrakchi, R. V. Johnson, and A. R. Tanguay, Jr., "Polarization Properties of Photorefractive Diffraction in Electrooptic and Optically Active Sillenite Crystals (Bragg Regime)", J. Opt. Soc. Am. B, Feb. 1986 (in press). (Invited manuscript in Special Issue on Materials for Optical Processing).
2. R. V. Johnson and A. R. Tanguay, Jr., "Optical Beam Propagation Method for Birefringent Phase Grating Diffraction", Opt. Eng., Feb. 1986 (in press). (Invited manuscript in Special Issue on Materials and Devices for Optical Information Processing).

### LIST OF PRESENTATIONS

1. R. V. Johnson and A. R. Tanguay, Jr., "Optical Beam Propagation in Anisotropic Media", 1985 Annual Meeting of the Optical Society of America, Washington, D. C., Oct. 1985.
2. A. Marrakchi, R. V. Johnson, and A. R. Tanguay, Jr., "Readout Optimization of Volume Holograms in Bismuth Silicon Oxide", 1985 Annual Meeting of the Optical Society of America, Washington, D. C., Oct. 1985.

### LIST OF THESES

1. Abdellatif Marrakchi El Fellah, "Real-Time Holography in Photorefractive Bismuth Silicon Oxide Crystals: Polarization Properties of Diffraction and Application to Spatial Light Modulation", University of Southern California, January, 1986.

## **TOWARD ROOM TEMPERATURE LASERS IN THE 3 $\mu$ m WAVELENGTH REGION**

**Elsa Garmire**  
**Research Unit QE1-1**

### **PROGRESS**

Finishing up work started during the last research period, Graduate Student Tom Hasenberg has successfully fabricated double carrier confinement quaternary lasers with threshold comparable to that of a simple double heterostructure. Two quaternary active layers, of 0.21 and 0.24  $\mu$ m thickness are separated by a very thin InP layer and stripe geometry lasers have been fabricated with threshold densities of 1.0 ka/cm<sup>2</sup> and threshold currents of 40 mAmps.

Problems with high forward resistance occurred because of some oxy-nitride left in the stripe region. In addition, problems with short lifetime due to oxygen contamination of the LPE growth systems have now been eliminated. We are in the process of a final series of growths which will be on p-substrates. This should result in a novel new structure - the p-substrate DCC, which should be more reliable and temperature-independent than any previously grown quaternary laser.

A new student, Nan Jokerst, has been introduced to the program, with the intent of studying longer wavelength lasers. This study is composed of two parts - one to determine the ability to grow by liquid phase epitaxy a double heterostructure of appropriate composition to properly confine carriers and light, leading to low threshold lasers. The second is to develop a method for measuring Auger recombination. In the former problem, she has found that phase diagrams indicate the LPE is possible. In the second, she has identified the technique introduced by Olshansky at GTE, which uses small signal modulation, as the most appropriate measurement of Auger recombination.

### **LIST OF PUBLICATIONS**

1. E. Garmire, "Double Carrier Confinement of GaInAsP Lasers." In preparation.
2. E. Garmire, "Tolerances on Locked Semiconductor Laser Arrays." In preparation.

**LIST OF PRESENTATIONS**

1. "Double Carrier Confinement GaInAsP Lasers Operating at 1.3 $\mu$ m." Presented by either Tom Hasenberg or Elsa Garmire at IEEE LEOS, Los Angeles, CA, Aerospace Corporation, Hughes, TRW, Los Angeles, CA, Sandia, Albuquerque, NM, and Kodak, Rochester, NY, 1985.
2. "The Tolerances on Locked Semiconductor Arrays." Presented by Elsa Garmire at The Physics of Quantum Electronics Conference, Snowbird, Utah, 1985; and IEEE LEOS Workshop on Semiconductor Lasers, Baltimore, MD, 1985.



## **A SPECTROSCOPIC STUDY OF BASIC PROCESSES IN ELECTRICALLY EXCITED MATERIALS**

**Martin A. Gundersen**  
**Research Unit QE1-2**

### **PROGRESS**

We have published several papers that have contributed to the development of serious interest in the physical principles responsible for high power switch limitations.<sup>1-5</sup> These include the conductivity under conditions of high current, laser induced fluorescence as a diagnostic in an operating thyatron, development of a laboratory data acquisition system for pulsed power, a quantitative model of the argon high current discharge, and delineation of the relationship between current and plasma parameters. Laser induced fluorescence has been used to measure excited state atomic hydrogen populations in a high current thyatron.

The program addressed properties of the bulk plasma including transport, the electron distribution function, the populations of specific excited states, and device development. This is needed for the development of a new and different generation of gas phase devices, and thus will be especially useful as device concepts are developed that are based on energy transfer processes involving specific quantum states, such as light assisted opening switches and other optogalvanic devices. Further, the development of optical diagnostic methods will provide an important additional benefit to DoD laboratory research. We think that this quantitative approach offers the highest probability for payoff in terms of new devices based on new concepts.

### **LIST OF PUBLICATIONS**

1. "Electron Temperature and Ionization Degree Dependence of Electron Transport Coefficients in Monatomic Gases," D.A. Erwin and J.A. Kunc, Phys. of Fluids, in press (1985).
2. "Collisional-radiative Coefficients from a Three-level Atomic Model in Non-equilibrium Argon Plasmas," C. Braun and J.A. Kunc, J. Chem. Phys., submitted (1985).

**LIST OF PRESENTATIONS**

1. "Recent Advances in Thyratrons and Glow Discharge Switches," M.A. Gundersen, Seminar, April 8, 1985, Massachusetts Institute of Technology.
2. "Fundamental Processes in High Current Glow Discharge Switches," M.A. Gundersen, J.A. Kunc, D. Erwin and C. Braun, Fifth IEEE Pulsed Power Conference, June 10-12, 1985, Washington, D.C.
3. "Plasma Diagnostics using Laser-Induced Fluorescence," D.A. Erwin and M.A. Gundersen, Fifth IEEE Pulsed Power Conference, June 10-12, 1985, Washington, D.C.
4. "A Comprehensive Microcomputer Based Data Acquisition System for Pulse Power Research," C. Braun, E. Bask, J. De Barros, P. Cheung, and J. Andras, Fifth IEEE Pulsed Power Conference, June 10-12, 1985, Washington, D.C.
5. "A Theoretical and Experimental Study of High Current Discharges in Argon," C. Braun, J.A. Kunc, and M.A. Gundersen, Fifth IEEE Pulsed Power Conference, June 10-12, 1985, Washington, D.C.
6. "Intrinsic Relationships between Current and Plasma Quantities in Thyratrons," D.A. Erwin, J.A. Kunc, and M.A. Gundersen, Fifth IEEE Pulsed Power Conference, June 10-12, 1985, Washington, D.C.
7. "Collisional-Radiation Coefficients from a Three-Level Atomic Model in Argon Plasmas," C. Braun and J.A. Kunc, NATO ASI Workshop, June 23-July 5, 1985, Pitlochry, Scotland.
8. "Plasma Radiation Fundamentals," J.A. Kunc, NATO ASI Workshop, June 23-July 5, Pitlochry, Scotland.
9. "Plasma Diagnostics using Laser Induced Fluorescence," D.A. Erwin and M.A. Gundersen, NATO ASI Workshop, June 23-July 5, 1985, Pitlochry, Scotland.
10. "Laser-induced Fluorescence Diagnostics in High-current Glow Discharge Plasmas," D. Erwin and M.A. Gundersen, 18th Annual Gaseous Electronics Conference, Monterey, California, October 15-18, 1985.

## OPTICAL SWITCHING

William H. Steier  
Research Unit QE1-3

### PROGRESS

The photorefractive effect in high resistivity semiconductors is a potentially large, fast, nonlinear effect for use in optical switching. Measurement of the photorefractive effect in Cr doped GaAs using two wave mixing have been initiated. The goal of these measurements is to determine the magnitude and rise time of the index of refraction changes as a function of laser intensity, applied electric fields, and moving gratings.

Two wave mixing is a convenient method for measuring the photorefractive effect in which the energy transfer between two beam interfering within the photorefractive active material is measured. Measurements on Cr doped GaAs ( $\rho = 10^6 \Omega\text{-cm}$ ) at  $1.06\mu$  show a saturated gain of  $0.48\text{cm}^{-1}$  at a grating wavelength of  $1.0\mu$ . The laser is polarized along a  $\langle 111 \rangle$  crystal axis and the grating is oriented to produce a space charge field along a  $\langle 111 \rangle$  axis. This is the optimum condition for a  $43\text{m}$  crystal. This measured gain is consistent with the predicted value.

The gain is not dependent on the laser intensity but the grating formation time should be linearly dependent on the intensity. At the intensities used in this experiment ( $5\text{ W/cm}^2$ ), the predicted grating formation time is  $40\mu\text{sec}$ . The observed times qualitatively agree with this value, but accurate measurement has not been possible because of noise.

The experiment is now being modified to apply D.C. electric fields to the sample and to measure the gain as a function of applied field and grating wavelengths. Theory predicts a significant increase in the gain with applied fields and when the grating is moving. The experiment is also being modified to create a moving grating by frequency shifting one of laser beams using a moving mirror.

**LIST OF PUBLICATIONS**

1. G. Albanese and W.H. Steier, "Measurements of Two Wave Mixing in Photorefractive GaAs," IEEE LEOS Los Angeles Chapter Meeting, Nov. 14, 1985.

## SELF-PUMPED OPTICAL PHASE-CONJUGATING LASER RESONATOR CAVITIES

Jack Feinberg  
Research Unit QE1-4

### PROGRESS

We have been investigating the properties of photorefractive phase-conjugators, as described below.

1. We recently completed a series of experiments in which we altered the photorefractive properties of a  $\text{BaTiO}_3$  crystal by oxidation and reduction treatments. We were able to:

- a) change the sign of the dominant photorefractive charge carriers,
- b) convert an inactive crystal to an active one,
- c) improve the high-speed time response of the crystal by making it scale linearly with optical intensity.

The last accomplishment is especially important for applications in which a phase conjugator is used inside the resonator cavity of a pulsed laser. In order to correct the optical distortions present in the resonator cavity, the phase conjugator must have a response time comparable to the (thermal) distortion rate. By making the time response of the  $\text{BaTiO}_3$  scale linearly instead of sublinearly as a function of optical intensity, high-speed operation can now be achieved with about 100 times less optical intensity than previously estimated.

The results of this work will be published in the February, 1986, issue of the Journal of Optical Society of America.

2. The principal investigator previously demonstrated that a cw dye laser with a phase-conjugating mirror will change its own output wavelength automatically. The mechanism of this "self-scanning" was not understood, although it was demonstrated to be due to a spontaneously moving photorefractive grating inside the  $\text{BaTiO}_3$  phase conjugator. We have completed a series of experiments to unravel the physical mechanism responsible for this grating motion. We show that grating motion in

photorefractive materials can cause an increase in the four-wave mixing gain due to a competition between four-wave and two-wave mixing in the material. We show good agreement between this theory and our experimental results.

The results of this research have been recently published in Physical Review Letters, 55, 821 (1985).

3. We have also initiated research into the high-speed behavior of a photorefractive BaTiO<sub>3</sub> crystal, using an intense beam from a pulsed dye laser. Preliminary work has determined an approximate damage threshold for a clean BaTiO<sub>3</sub> crystal surface, and has demonstrated high-speed grating erasure with intense laser pulses. Further work is in progress.

#### LIST OF PUBLICATIONS

1. S. Ducharme and J. Feinberg, "Altering the photorefractive properties of BaTiO<sub>3</sub> by reduction and oxidation," to be published in J. Opt. Soc. of America-B February, 1986.
2. K.R. MacDonald and J. Feinberg, "Enhanced four-wave mixing by use of frequency-shifted optical waves in photorefractive BaTiO<sub>3</sub>," Phys. Rev. Lett., 55, 821 (1985).

#### LIST OF PRESENTATIONS

1. "Phase-locking lasers with phase conjugation", J. Feinberg and G.D. Bacher, Gordon Conference on Lasers and Nonlinear Optics, August, 1985, Wolfeboro, New Hampshire.
2. "Frequency shifts and laser locking with phase conjugation," J. Feinberg, Opt. Soc. of America Annual Meeting, October, 1985, Washington, D.C.
3. "Phase conjugation," J. Feinberg, Opt. Soc. of America Annual Meeting, October, 1985, Washington, D.C.
4. "Altering the photorefractive properties of BaTiO<sub>3</sub>," S.P. Ducharme and J. Feinberg, Opt. Soc. of America Annual Meeting, October, 1985, Washington, D.C.
5. "Why does a BaTiO<sub>3</sub> self-pumped phase conjugator produce a frequency-shifted output beam?" K.R. MacDonald and J. Feinberg, Opt. Soc. of America Annual Meeting, October, 1985, Washington, D.C.

## ANALYSIS AND SYNTHESIS OF PARALLEL PROCESSING SYSTEMS

D.I. Moldovan and G. Bekey  
Research Unit IE1-1

### PROGRESS

During the period 4/1/85 - 12/31/85 our research has focused on two main areas:

1. Parallelism in production systems used in artificial intelligence. We have developed a technique to model production systems using graph grammar theory. Then, we used these models to detect parallelism in production systems based on the interdependencies between rules. Finally we examined hardware requirements for implementing parallel production systems.

2. Mapping permutation algorithms into array processors. Our effort in this area was directed towards relating the characteristics of numerical algorithms to the characteristics of array processors. We have devised procedures to modify algorithm permutations in order to map them into interconnection networks such as mesh-connection, perfect shuffle and others.

### LIST OF PUBLICATIONS

1. D.I. Moldovan and Y.W. Tung, "SNAP: A VLSI Architecture for Artificial Intelligence Processing", Journal of Parallel and Distributed Computing, 2 No. 2, May 1985.
2. J.A.B. Fortes and D.I. Moldovan, "Parallelism Detection and Algorithm Transformation Techniques Useful for VLSI Architecture Design," Journal of Parallel and Distributed Computing, 2 No. 3, August 1985.
3. T.C. Lin and D.I. Moldovan, "Tradeoffs in Mapping Algorithms into Array Processors," Proc. 1985 International Conf. on Parallel Processing, Aug. 1985.
4. F. Tenorio and D.I. Moldovan, "Mapping Production Systems into Multiprocessors," Proc. 1985 International Conf. on Parallel Processing, August 1985.
5. T.C. Lin and D.J. Moldovan, "On Mapping Parallel Algorithms into Mesh-Connected SIMD Computers," submitted to Sixth International Conference on Distributed Computing Systems, May 1986.

6. T.C. Lin and D.I. Moldovan, "M<sup>2</sup>-Mesh: An Augmented Mesh Architecture," submitted to 13th International Symposium on Computer Architecture, June 1986, Tokyo, Japan.

#### LIST OF PRESENTATIONS

1. "Parallel Processing of Production Systems," by Dan Moldovan at University of California in San Diego, in November 1985.
2. "Mapping Production Systems into Multiprocessors," by Dan Moldovan, at 1985 International Conference on Parallel Processing, August 1985.
3. "Tradeoffs in Mapping Algorithms to Array Processors," by T.C. Lin at 1985 International Conference on Parallel Processing, August 1985.



## BASIC RESEARCH IN C<sup>3</sup> DISTRIBUTED DATABASES

VICTOR O.K. LI  
Research Unit IE1-2

### PROGRESS

We have developed an effective approach to distributed query processing problems. It has been shown that a general query processing problem is N-P hard. Therefore, obtaining the optimal solution is computationally expensive. The alternative would then be the development of heuristics. We have proved several important optimality properties of query processing programs. These optimality properties let us check whether a given query program (generated by a heuristic, for example) is optimal. We have also developed improvement algorithms for star queries which allow us to improve a given program if it is not optimal. Our results are described in Pub. 1 in the next section. We are presently trying to extend the algorithm to more general queries. In addition, a new approach to distributed query processing, known as the relation-partitioning approach, has been developed. (See Pub. 4 in the next section.)

We have also developed the Event-Based Reliability Model (EBRM) for communications networks. This model allows one to model and evaluate the reliability/availability of a network in which the components have dependent failures. Details of this model are given in Pub. 2 and 3 in the next section.

### LIST OF PUBLICATIONS

1. Chen, A.L.P. and Li, V.O.K., "An Optimal Algorithm for Processing Distributed Star Queries." IEEE Trans. on Software Engineering, SE-11, 1107 (Oct. 1985).
2. Lam, Y.F. and Li, V.O.K., "Reliability Modeling and Analysis of Communication Networks with Dependent Failures." To appear in the IEEE Trans. on Communications, Jan. 1986.
3. Lam, Y.F. and Li, V.O.K., "Reliability Modeling and Analysis of Communications Networks with Dependent Failures," Proc. IEEE INFOCOM, Washington, D.C., March 1985.
4. Wang, C.P. and Li, V.O.K., "The Relation-Partitioning Approach to Query Processing in Distributed Databases." To appear in Proc. IEEE Data Engineering Conference, Los Angeles, California, Feb 1986.

5. Li, V.O.K., "Performance Models of Timestamp Ordering Synchronization Algorithms in Distributed Databases," submitted for publication.

## IMAGE TEXTURE RESTORATION AND ANALYSIS USING NONSTATIONARY MODELS

A.A. Sawchuk  
Research Unit IE1-3

### PROGRESS

Our work in image texture segmentation is based on the concept of using a multiple-resolution feature set in a hierarchical decision process. The goal is to combine information from features generated at varying resolutions so as to yield a more accurate segmentation than can be achieved using a single resolution feature set. The improvement in classification accuracy is most noticeable when the statistics of the feature set non-stationary statistics.

The key to implementing the hierarchical decision process is to be able to identify the data points that are affected by the mixture of statistics. The basic technique being used is to perform a preliminary analysis of the data prior to doing any classification with the goal of determining which classes will be most affected by the nonstationary statistics. This allows the classification algorithm to later identify the image data points with a higher than normal likelihood of begin from a mixture of classes.

At the present time, four methods for detecting the mixture points have been examined. The methods are referred to as: hyperspheres, hyperplanes, hypercylinders, and near-optimum. All four methods are similar in that a region in the feature space is determined for accepting or rejecting the choice of the classification algorithm. Points that are have the classification choice rejected are placed in a null class and are classified later in the decision process. The basic differences between the the four methods is in the shape of the rejection or null class region.

The preliminary results from the first two methods were discussed in the previous progress report. The results using the hypersphere and hyperplane methods were encouraging but the methods proved to be too restrictive in allowing classification. The third and fourth methods were designed to overcome these deficiencies and are very similar in that the rejection region is limited to being just around the potential mixture points. In the hypercylinder method, the rejection region is a cylinder of a pre-

determined radius surrounding the line segment that connects two class means. The expected location of any point that is a mixture of the two classes is on this line. The near-optimum method is an extension of the hypercylinder method using a rejection region based on Bayes decision theory. The region shape is determined by the approximate probability density of the potential mixture points along the line segment. At the present time, the third method described (using the hypercylinders) appears to work best. It performs better than the other methods and is acceptable from the standpoint of computational complexity.

Work is currently under way to examine various techniques for including spatial information in the hierarchical decision process. Current efforts have centered around using a test of the coherence of a classified pixel with other neighboring pixels. Results have been shown that the inclusion of the spatial information can improve the final classification accuracy.

The final hierarchical decision process is also being studied to determine the best way to use all of the available information to enhance the segmentation of the image. This involves combining the multiple classification results from the various feature sets with the spatial information obtained with the coherence measurement.

#### LIST OF PRESENTATIONS

1. A. G. Weber, A. A. Sawchuk, "Texture Segmentation with Multiple Window Sizes," presented at Optical Society of America 1984 Annual Meeting, San Diego, CA, October 1984.
2. A. G. Weber, A. A. Sawchuk, "Segmentation of Textured Images," presented at Optical Society of America Topical Meeting on Machine Vision, Incline Village, NV, March 1985.

## **INFOBASE: AN INFORMATION MANAGEMENT ENVIRONMENT FOR PERSONAL WORKSTATIONS**

**Dennis McLeod  
Research Unit IE1-4**

### **PROGRESS**

During this research period, our work has focused on devising and experimentally implementing an object-oriented information management environment to support design engineering databases. The principal thrust of this research has been directed towards the goal of identifying the fundamental scientific information representation and presentation issues as regards the design engineer who is involved in developing and evolving a large engineered design object. A main focus of our work has involved experimentally analyzing the information management requirements of the designer of a VLSI chip, and devising an approach to supporting the information management needs of such a user. The results of our work on the principal aspects of this research problem are described in [1, 2, 4, 5, 7].

A further focus of this research has been on supporting dynamic information sharing among a collection of autonomous databases. To drive our work in this area, we have investigated the sharing requirements of a collection of collaborating design engineers, and have devised and experimentally implemented a novel approach to information sharing [3]. We have also examined efficiency issues vis-a-vis object-oriented database environments, and have devised concepts and algorithms to realize efficiency in the face of highly dynamic performance requirements [6].

During the proposed research period, we plan to devise and experimentally implement techniques and mechanisms to allow VLSI designers to devise, refine, and specify components. We shall develop and refine the scientific concepts underlying these requirements, and realize them in an experimental prototype.

**LIST OF PUBLICATIONS**

1. King, R., and D. McLeod, "Semantic Database Models", in Principles of Database Design (editor S. B. Yao), Prentice Hall, 1985.
2. King, R., and D. McLeod, "A Database Design Methodology and Tool for Information Systems", ACM Transactions on Office Information Systems, 3, 2 (January 1985).
3. Heimbigner, D., and D. McLeod, "A Federated Architecture for Information Management", ACM Transactions on Office Information Systems, 3, 253 (April 1985).
4. Afsarmanesh, H., D. Knapp, D. McLeod, and A. Parker, "An Extensible, Object-Oriented Approach to Databases for VLSI/CAD", Proceedings of International Conference on Very Large Databases, Stockholm, Sweden, August 1985.
5. Afsarmanesh, H., D. Knapp, D. McLeod, and A. Parker, "An Approach to Engineering Design Databases with Applications to VLSI/CAD", Proceedings of International Symposium on New Directions in Computing, Trondheim, Norway, August 1985.
6. Ahad, R., and D. McLeod, User-Assisted Semi-Automatic Design of Physical Databases, Technical Report, Computer Science Department, University of Southern California, April 1985.
7. Narayanaswamy, K., W. Scacchi, and D. McLeod, "A Database System to Support the Design and Evolution of Large Software Systems", Technical Report, Computer Science Department, University of Southern California, October 1985, submitted to IEEE Transactions on Software Engineering.

**LIST OF PRESENTATIONS**

1. McLeod, D., "Object Management and Sharing in Distributed, Autonomous Database Systems", Computer Science Colloquium, Stanford University, Palo Alto CA, April 1985 (invited talk).
2. McLeod, D., "An Extensible, Object-Oriented Approach to Databases for VLSI/CAD", International Conference on Very Large Databases, Stockholm, Sweden, August 1985 (conference presentation).
3. McLeod, D., "An Approach to Engineering Design Databases with Applications to VLSI/CAD", International Symposium on New Directions in Computing, Trondheim, Norway, August 1985 (conference presentation).

**LIST OF THESES**

1. Dr. Rafiul Ahad, Ph.D. in Computer Science granted May 1985, Thesis title: "User-Assisted Semi-Automatic Design of Physical Databases".
2. Dr. Hamideh Afsarmanesh, Ph.D. in Computer Science granted August 1985, Thesis title: "3DIS: An Extensible, Object-Oriented Framework for Information Modelling and Access".
3. Mr. K. V. Baparao, Ph.D. Candidate in Computer Science (degree expected December 1985), Thesis title: "A Model and Methodology for the Design and Evolution of Engineering Databases".

## REDUCED MODELLING THROUGH OPTIMAL PHASE MATCHING

Edmond A. Jonckheere and Leonard M. Silverman  
Research Unit IE1-5

### PROGRESS

Over the past few years, this research unit has been mainly concerned with reduced modelling of both deterministic and random systems. Applications include, but are not limited to, the simplification of overly complex models of large flexible space structures with more vibration modes that can be handled by currently existing control design packages, the reduction of feedback controllers down to a size that can be computer implemented, or the low order modelling of a stochastic process identified through a massive amount of data.

Last year, we formulated the so-called "phase-optimal reduced modelling problem," see [1], [2], and left some advanced topics for further research. In this approach to reduced modelling, the Bode phase diagrams of both the full order and the reduced order transfer functions should be as close as possible. It is our pleasure to report that the theoretical solution of this problem has been almost completely worked out during the period of time 4/1/85 - 12/31/85; see [5], [7], [8]. In addition, we have come back to what has always been the driving motivation of this JSEP work unit -- the control of complex large space flexible structures through a computer-implementable compensator; see [8]. This indeed requires the low order modelling of the original modal representation of the structure that contains more vibration modes than can possibly be handled as well as the simplification of the controller. We have applied the reduced modelling techniques developed in this JSEP work unit to the experimental flexible truss structure of TRW. We have been very successful in designing very low order controllers for such a complex structure. Our designs were experimentally verified in real laboratory experiments that were conducted at TRW; see [8].

Aside from the main stream of research effort, we have also been active in the area of linear quadratic singular control and estimation problems, see [6], [9], the main concrete application being the singular Kalman Bucy filtering problem, that had remained largely unsolved prior to our work [6].



## LIST OF PUBLICATIONS

1. E.A. Jonckheere and J.W. Helton, "Power spectrum reduction by optimal Hankel norm approximation of the phase of the outer spectral factor," IEEE Transactions on Automatic Control, **AC-30** (December 1985).
2. P. Harshavardhana and E. A. Jonckheere, "Spectral factor reduction by phase matching -- the continuous-time single-input single-output case," International Journal of Control, vol. **42**, 43 (1985).
3. Ph. C. Opdenacker and E.A. Jonckheere, "A contraction mapping preserving balanced reduction scheme and its infinity norm error bounds," IEEE Transactions on Automatic Control, to appear.
4. Ph. C. Opdenacker and E.A. Jonckheere, "A characterization of passive systems through their closed loop LQG characteristic values," IEEE Transactions on Automatic Control, to appear.
5. K. Glover and E. A. Jonckheere, "A comparison of two Hankel norm methods for approximating spectra," International Symposium on the Mathematical Theory of Networks and Systems, Stockholm, Sweden, June 1985.
6. A. Kitapci, E. Jonckheere, and L. Silverman, "Singular optimal filtering," International Symposium on the Mathematical Theory of Networks and Systems, Stockholm, Sweden, June 1985.
7. Ph. C. Opdenacker and E. A. Jonckheere, "A state space approach to approximating by phase matching," International Symposium on the Mathematical Theory of Networks and Systems, Stockholm, Sweden, June 1985.
8. Ph. C. Opdenacker, "Balanced model order reduction techniques and their applications to large space structure problems, " Ph.D. dissertation, Department of Electrical Engineering--Systems, University of Southern California, June 1985.
9. A. Kitapci, "System structure and singular control problems," Ph.D. dissertation, Department of Electrical Engineering--Systems, University of Southern California, June 1985.

## RESEARCH IN COMPUTER VISION

**Rama Chellappa**  
**Research Unit IE1-7**

### PROGRESS

The goal of this research unit is to develop model based approaches for some computer vision problems. The potential application of this research are in smart interpretation of aerial images, and intelligent tracking of moving objects. The progress made over the past nine months in these two specific areas are summarized below:

#### **Feature Extraction**

We have recently developed an edge detector using the zero crossings of the second directional derivatives of a random field model. The image pixels in a local region are represented by a 2-D autoregressive model whose parameters are adaptively estimated over the image. Due to this modelling assumption, the first and second directional derivatives are functions of parameter estimates. An edge is detected if the second directional derivative is negatively sloped and the first derivative is above a threshold. Good results have been obtained using this edge detector. Details of this work may be found in [1]. Texture segmentation is one of the challenging problems in computer vision. We have developed a texture segmentor using an estimation theoretic approach. By assuming that the textures are represented by an interpolative model, we have derived a maximum likelihood segmentor. Details of this work may be found in [2].

#### **Estimation of Object Motion Parameters from a Sequence of Noisy Images**

Estimation of object motion from a sequence of images is an important problem in image analysis and computer vision. Currently known techniques for object motion estimation use up to 3 frames of data but a large number of match points per frame to overcome the noise in the image frames. Very often imagery from video or forward looking infrared (FLIR) sensors is of relatively poor resolution making the identification of match points extremely difficult; however, these image are usually available at a high rate.

We have developed an algorithm for estimation of object motion parameters from a sequence of say 20-30 noisy image frames, but requiring less than 3 match points/frame.

The problem considered is that of a rigid body undergoing unknown rotational and translational motion. The noisy measurement data consist of a sequence of noisy image coordinates of two or three object correspondence points. By modelling the object dynamics as a function of time, estimates of the model parameters (including motion parameter) have been extracted from the data using recursive techniques. Our approach permits a desired degree of smoothing to be achieved through the use of an arbitrarily large number of frames. Details of this work may be found in [3].

#### LIST OF PUBLICATIONS

1. Yitong Zhou and Rama Chellappa, "Edge Detection Using Zero Crossings of Second Directional Derivatives of a Random Field Model", (Accepted for presentation at the Intl. Conf. on Acoust., Speech Signal Processing, Tokyo, Japan, April 1986)
2. S. Chatterjee and Rama Chellappa, "Maximum Likelihood Texture Segmentation Using Gaussian Markov Random Field Models", Proc. Conf. on Computer Vision and Pattern Recog., San Francisco, CA, pp. 215-217, June 1985.
3. T.J. Broida and Rama Chellappa, "Estimation of Object Motion Parameter from Noisy Images", Proc. Conf. on Computer Vision and Pattern Recog., San Francisco, pp. 82-88, June 1985. (Also to appear in IEEE Trans. Patt. Anal. Mach. Intell., PAMI-8, (Jan. 1986).
4. P.F. Singer and R. Chellappa, "Machine Perception of Partially Specified Planar Shapes," Proc. Conf. on Comput. Vision and Pattern Recog., San Francisco, pp. 497-502, June 1985. (To be submitted for IEEE Trans. Patt. Anal. Mach. Intell.)

#### LIST OF PRESENTATIONS

The first three papers were presented at the 1985 IEEE Conf. on Computer Vision and Pattern Recognition, San Francisco, June 1985.

1. Maximum Likelihood Texture Segmentation Using Gaussian Markov Random Field Models
2. Estimation of Object Motion Parameters from Noisy Images.
3. Machine Perception of Partially Specified Planar Shapes.
4. "Edge Detection Using Zero Crossings of Second Directional Derivatives of a Random Field Model", Fourth ASSP Workshop on Multidimensional Signal Processing, Leesburg, Va. Oct. 1985.

5. "Model Based Approaches for Some Low Level Vision Problems", Invited Lecture at the Advanced Target Recognizer Working Group Meeting, Naval Weapons Center, China Lake, Oct. 22, 1985.

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